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PNEUMATICALLY DRIVEN LOUDSPEAKER AND ITS USE

TECHNICAL FIELD

The invention presented here concerns a pneumatically driven loud speaker comprising at least one chamber having higher pressure than the surroundings an at least one chamber with lower pressure than the surroundings, as well as a modulatable opening between the respective chambers and the surroundings.

BACKGROUND

Pneumatically driven loud speakers are previously known. These loud speakers comprise a chamber with positive pressure as well as several openings in one wall of the chamber. Over these openings is a slide which can move in such a way that it in one setting closes the openings and in another setting opens them. By moving the slide back and forth with a certain frequency a sound wave of corresponding frequency is obtained by the pulsating emission of compressed air through the openings.

Pneumatic loud speakers have the advantage over other known types of loud speaker in that they give a high output at the same time as they take up relatively little space. This makes them especially suitable for use in active noise suppression etc.

A drawback in using electro-pneumatic loud speakers is, however, that they are markedly non-linear. Previous attempts at linearization concerns discrete tones only. This means that a linear relationship between electrical input signal and acoustic wave over a wider spectrum, which is a prerequisite for broadband damping active noise suppression systems, has not yet been possible to achieve.

Factors contributing to the strong non-linearity in the said type of known pneumatic loud speaker is that the positive pressure presses the slide against the bracket in which it slides, which causes friction. Furthermore, the intermittently emitted airflow displays a markedly asymmetrical wave characteristic because of the non-linearity.

PURPOSE OF THE INVENTION

It is thus the purpose of the invention presented here to yield a more linear pneumatically driven loud speaker, which is easier to control and which can be used over a greater frequency spectrum.

This objective is achieved by a pneumatic loud speaker according to the attached claims.

SUMMARY OF THE INVENTION

According to an aspect of the invention it involves a pneumatically driven loud speaker comprising at least one chamber having higher pressure than the surroundings and at least one chamber with lower pressure than the surroundings. Subsequently the term chamber is used in the singular, which however does not exclude the eventuality that the chamber can be divided into several interacting chambers. The chambers are each supplied with at least one modulatable opening to the surroundings, making it possible to alternately open and close the high pressure and low pressure chambers to the surroundings by means of a valve mechanism, which means for example that the opening to the high pressure chamber is opened while the opening to the low pressure chamber is closed and vice versa. This modulation of the opening proceeds at the frequency selected. In this way the loud speaker's efficiency and output can be increased. In this context the term surroundings is understood to mean the environment in which the loud speaker is operating, which normally means that the surroundings is the air space around the loud

speaker, so that the surroundings are at atmospheric pressure. Other ambient pressures are naturally possible.

According to the aspect of the invention the air is alternately pressed out from and sucked back into the loud speaker. In this way there is a superposing of an exhaust characteristic with an essentially inverted suction characteristic. Both these curves are strongly non-linear, but with the superposing a greater symmetry is achieved in the characteristic. As a consequence the loud speaker produces a less distorted signal and is therefore easier to control compared to if only one chamber with pressure differing from the surroundings is used.

The invention is especially suitable for use in active noise suppression because of its high output per weight and area unit, as well as being able to operate within a wide range of frequencies.

Additional beneficial features of the invention are evident from the following description and claims. A number of variations of the embodiment are described, where mainly the valve mechanism's function varies in a number of different ways.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now for the purpose of exemplification be described in more detail, with the help of embodiment examples and with reference to the attached drawings, in which:
Fig 1a shows a schematic cross-sectional view through a loud speaker cell according to one embodiment of the invention presented here;
Fig 1b shows a loud speaker cell as that in Fig 1a, but with an alternative drive mechanism;
Fig 2 shows a perspective cut away view of a loud speaker with several loud speaker cells as in Fig 1;
Fig 3 shows schematically a loud speaker according to the invention with

variable direction properties;

Fig 4 shows a part of a turbo-fan engine with loud speakers according to the invention for active noise suppression, shown partly in cut away; and

Fig. 5 shows an alternative embodiment of the invention, for use in active noise suppression in ventilation ducts.

Fig 6a - 6c shows schematically cross-sectional views of a loud speaker with rotating valve mechanisms.

Fig 7a and Fig 7b shows section views of the loud speaker as in 6b in two planes perpendicular to each other.

Fig 8a - 8e shows schematically cross-sectional views of a loud speaker with waddling valve mechanisms.

Fig 9 shows a schematic cross section of a loud speaker according to the aspect of the invention where the valve mechanism is comprised of cones which alternately close the openings to the surroundings.

DESCRIPTION OF PREFERRED EMBODIMENTS

Fig 1a shows schematically a loud speaker cell according to an embodiment of the invention presented here. The loud speaker comprises at least one chamber, preferably several chambers 1,2 with alternating positive and negative pressure stacked one on the other in a sandwich-like construction. Through the openings in these chamber walls a sliding tube 3 is fitted. This tube is preferably open at both ends. Moreover, the tube has at least one set of openings 4 at essentially the same height in the tube's envelope surface. In this way, when the openings are within the positive pressure chamber 1, air will flow in through the openings 4, continue along the tube 3 and out through the opening at the end. When the tube is slid so that the openings instead end up in the negative pressure chamber 2 air is instead sucked into the chamber from the end opening via the tube. By sliding the tube to and fro at a certain frequency a pulsating air wave is produced, and from this a sound is generated. Alternatively, the chambers can instead be arranged in sectors around the tube, so that the the tube makes a radial motion instead on an axial

one. Even in this case, however, the motion is to and fro. By having several positive and negative pressure chambers the frequency of the sound can be increased since the side openings 4 in the tube pass several positive and negative pressure chambers during each stroke. The tube is , however, best furnished with several sets of side openings. The number of such sets of side openings is preferably the same as the number of chambers with positive pressure or chambers with negative pressure. Moreover, the sets of side openings are preferably arranged vertically, that is to say in the direction of the axis of the tube, and separated so that each opening is either in the positive pressure chamber or negative pressure chamber. This leads to an increase in the air flow through the tube, and hence the acoustic pressure and output of the loud speaker, while the length of the stroke of the tube decreases. Thus the positive pressure and negative pressure in each chamber can be maintained at moderate levels, allowing the tube's walls to be made thin. Consequently, the tube can move more easily and requires less energy to do so. By using chambers with positive pressure as well as chambers with negative pressure a symmetry in the characteristic of the output sound is achieved, since the air is moved to and fro instead of merely being pressed out and being shut off. One gets a superposing of two separate non-linear, but essentially inverted, signals, which produces a more symmetric curve, although still non-linear. This makes it easier to reproduce sound and easier to control the loud speaker.

The tube is operated by a driving mechanism, which can be hydraulic, pneumatic or thermally generated. However, the preferred mode is electromagnetic by means of a coil wound round the lower end of the tube. For many applications a piezo-electric drive would be possible, in which case the sandwich-like construction described above can be employed to achieve a high output despite the short stroke motion (displacement). The piezo-electric drive can even have some form of gear so as to efficiently obtain a low frequency, which is often desirable since piezo-electric cells often operate at a higher frequency (usually about 50-100 kHz), while the loud speaker is

normally used at considerably lower frequencies. An advantage of the piezo-electric drive is that the construction is very small and light, while the motion, i.e. the stroke lengths, of the modulatable openings is decreased. This results in both reduced friction between fixed and moving parts and lower distortion.

Fig. 1b shows a preferred type of piezo-electric drive mechanism. In this embodiment there is a rod 6 which is fixed to the frame and is inserted into the tube 3. Projecting out more or less perpendicularly from the rod are arms 7, which at their other extremities are attached to the inner wall of the tube 3. These arms are piezo-electric bending cells, which when activated produce an axial motion of the tube. Naturally, these bending cells can even be arranged in other ways. For example, several rods can be used, so that the bending cells extends in directions that intersect one another, or the rod can be placed in the centre from which the arms extend radially in different directions.

Furthermore, the loud speaker comprises pneumatic drive devices (not shown) for producing positive and negative pressure in the chambers. These pneumatic drive devices can be conventional pumps or fans, for example. The chambers can even be connected to available compressed-air systems.

The tube is preferably circular and preferably fits relatively tightly into the corresponding openings in the chamber walls. In addition, the side openings are preferably symmetrically placed, such as two openings opposite one another, or four openings arranged in a cross. In that way the resulting force which the pressure in the chambers has on the tube is essentially zero, so that the friction between the tube and the chamber walls is reduced and the tube slides more easily. As a result, the distortion is reduced in the loud speaker and it is easier to control. Alternatively, the tube can naturally have a cross sectional shape other than circular, for example elliptical, quadratic, rectangular, etc. Furthermore, it is possible to allow the tube to be slid diagonally to the chamber walls, even if it is preferred that the tube is slid

essentially perpendicular to the chamber walls, the latter of which is shown in the drawings.

If a tube 3 as described above is used it should be made shorter for generation of higher frequencies. If the tube is long a sound wave generated at the bottom of the tube will interfere with a sound wave generated at the top of the tube. This becomes a problem only if the length of the tube is of the same order of magnitude as the length of the sound wave at a specific frequency. This can be prevented if the tube is designed as a number of rings which constitute the active components of the valve body. The rings are connected to each other by means of circular springs in such a way that the rings perform a translation motion along the length of the tube at the speed of sound. The said undesired interference will not manifest itself, while energy will be supplied to the generated sound wave for each ring. At one end of the tube the change is passively or actively suppressed so that no reverberations of the wave motion arise.

In a preferred version of the invention Fig 6a-6c shows a loud speaker which is also designed to generate acoustic pressure at a certain frequency of choice. This version comprises a space 60 for fluctuating pressure, acoustic pressure, where the said space 60 is in contact with the surrounding air in which it is intended to produce acoustic pressure. There are openings 61 from the chamber with higher pressure 62 and openings 63 from the chamber with lower pressure 64 than the surroundings into the space 60 for fluctuating acoustic pressure. A valve mechanism in the form of a rotating valve body 65 located in the space 60 for the fluctuating pressure alternately opens the openings 61 and 63 to the high pressure chamber 62 and low-pressure chamber 64 respectively, whereby the desired acoustic pressure is generated in the space 60. The generated acoustic pressure is directed to the surroundings through the opening 66. The valve body 65 is rotated at a selected number of revolutions, which means that the frequency of the generated sound can be varied by adjusting the valve body's 65 rate of rotation.

The valve body 65 can be designed in an alternative way according to the figures 6a, 6b, and 6c. Characteristic for this version of the invention is that the valve body is made up of a rotation unit, where a part of the rotation unit consists of a cavity 67. When the valve body rotates in the valve space 60, the cavity, when facing the opening 61 to the high-pressure chamber 62, will allow a flow of air to the surroundings via the opening 66. Similarly, air from the surroundings flows via the opening 66 through the cavity to the low-pressure chamber via the opening 63, when the cavity 67 is facing the opening 63 during rotation of the valve body. The cavity 67 is thus designed to consist of a duct which, preferably in a radial direction, periodically connects with the openings to the high-pressure chamber and the low-pressure chamber. The duct is also designed so that it is connected to the surroundings at least during the said periods or alternatively that it is permanently connected with the surroundings. The duct can with advantage be designed so that it produces a favourable current. The cavity 67 is in one version designed so that the cavity constitutes a volume sector of the valve body with a certain sector angle about the axis of rotation of the valve body. In figure 6a the valve body is shown with a cavity 67 which constitutes a volume sector of 180° angle about the axis of rotation. Fig 6b is in the same way showing a cavity which constitutes a volume sector of 90° angle. It is of course possible to construct the the valve body's cavity with other sector angles. It is also possible to furnish the valve space with more than one opening from two low-pressure sources and with more than one opening from two high-pressure sources, whereby the valve body will open to a high-pressure and a low-pressure chamber more than once per revolution.

One embodiment of the valve where the valve space 60 has two openings to the high-pressure source and two openings to the low-pressure source is shown in Fig 6c. The valve body in fig 6c is, in addition, shown with a cavity 67 consisting of a duct 68 running through the the valve body. During rotation of the valve body the openings are alternately opened and closed to

the surroundings and axially to the valve body.

The valve body 65 can also be permitted to slide in the axial direction. The openings 61, 63 to the pressure sources can be given geometries such that the mouth area of the cavity open to the pressure sources change in accordance with the valve body's axial motion. By sliding the valve body in this manner it is possible to regulate the flow and therefore the acoustic pressure. It is convenient to use the said axial displacement within each rotation cycle of the valve body to monitor distortion which arises. This, however, requires quick adjustment of the displacement.

Fig 7a and 7b show section views of two different planes, the first of which is perpendicular to the valve body's axis of rotation and the other according to section A - A, in which the positioning of the valve body's 60 opening 66 to the surroundings is depicted.

A further variation of the loud speaker is shown in Fig. 8a-8e. The loud speaker according to Fig 8a-8b comprises a space 60 for fluctuating pressure, acoustic pressure, where the said space 60 is in contact with the surrounding air in which it is intended to create acoustic pressure. From both the chamber 62 with higher pressure and the chamber 64 with lower pressure than the surroundings to the space 60 for fluctuating acoustic pressure there are openings 61 and 63 respectively. A valve mechanism in the form of a rocking valve body 65 located in the space 60 for the fluctuating pressure opens alternately the openings 61 and 63 to the high-pressure chamber 62 and the low-pressure chamber 64 respectively, thereby generating the desired acoustic pressure in the space 60. The generated acoustic pressure is carried to the surroundings via the opening 66. The valve body 65 is rocked at the desired frequency, which means that the generated sound frequency can be selected by controlling the oscillation pattern of the valve body's 65 rocking motion.

For the rocking version the valve body 65 can be designed in an alternative

way according to figures 8a and 8e. The valve body is best made of an almost semi-spherical or semi-circular cylindrical body or other sector part of a sphere or cylindrical body. In other versions only the envelope surface of one of the said bodies can act as the valve body 65. With one of the said shapes both openings to the pressure sources are closed when the valve body is in neutral position according to Fig 8a. Fig 8b shows the valve body rocked to its first end position, at which the opening 63 to the low-pressure source is completely open, so that air from the surroundings can flow via the opening 66 towards the low-pressure source. Fig 8c illustrates the valve body's other end position, where the opening 61 to the high-pressure source is completely open, so that air from the high-pressure source flows out to the surroundings. The fluctuating flow of air which is produced here creates the desired sound.

By varying the cross-section segment of the valve body, by for example making the segment smaller, both openings to the pressure source can be held partly open when the valve body is in the neutral position, as shown in fig 8d. According to fig 8e the valve body will nevertheless be able to close an opening to a pressure source completely when it is in an end position. This arrangement produces a different acoustic character.

Even for the rocking version, the valve body 65 can be permitted to move in an axial direction, i.e. along its rocking axis, in the valve space 60. The openings 61, 63 to the pressure sources can have geometries such that the mouth area of the cavity open to the pressure sources changes in accordance with the valve body's axial motion. By moving the valve body in this manner it is possible to regulate the flow and thus the acoustic signal.

A further version of the loud speaker is show in fig 9. As above the purpose is to generate acoustic pressure at certain frequencies of choice. An ordinary siren according to known techniques consists of a source with compressed air (the pressure of which is higher than the surroundings) and a regulated discharge, which can be carried out, for example, using a mobile cone. This

solution is apparent if one considers the left part of fig 9. By moving the cone laterally at a certain frequency the air flow can be regulated and acoustic pressure is created. One drawback is that air is constantly flowing out of the system and thereby impairing efficiency. The version of the sound source according to fig 9 solves this by providing the sound source with a high-pressure source 62 with higher pressure than the surroundings and a low-pressure source 64 with lower pressure than the surroundings. The surroundings here means the pressure outside the opening 66. The opening 61 of the high-pressure source to the valve space 60 is supplied with a first cone 91 that interacts with the, in this version, conically shaped opening 61, whereby the first cone 91 opens or closes the opening 61, when the cone is moved to and fro in the cones axial direction. In a similar way, a second cone 92 opens and closes the flow to the low-pressure source 64, when this second cone is moved to and fro. The flow out from the high-pressure part and the flow in to the low-pressure part can be regulated individually by the to and fro movement of the respective cones. The cones 91 and 92 can be controlled individually or together by connecting the cones 91 and 92 with an axis. The sound that is produced by the loud speaker as a result of the fluctuating pressure at the opening 66 out to the surroundings will have a wider band than that from a conventional siren.

The loud speaker also consists of a control unit 5, which is connected to a drive mechanism for actively setting the valve mechanism in motion, i.e. sliding the tube or rotating the valve body or vibrating the reed according to the valve mechanism in question. By means of control signals the control unit controls the motion of the valve mechanism, and thus the generated acoustic signal. The control unit receives an incoming signal which indicates the desired outgoing signal. The control unit then performs a signal processing task in order to translate the desired signal to corresponding control signals for the desired motion of the valve mechanism. This translation can, for example, be done by a translation table which is established in advance by measurements, by direct functional correlation, or the like. Translation can

also be controlled by feedback control, by connecting the gauge 6 for detection of the generated sound to the control unit 5. Using the control unit 5 an essentially linear output characteristic for the loud speaker can be obtained over a wide frequency band. The control unit preferably contains an artificial neuron net, which one "teaches" to translate certain input signals to equivalent output signals, and which through "self-teaching" based on these known cases creates appropriate translations for other cases as well.

Fig 2 shows an embodiment where several loud speaker cells of the type described above are arranged together. In this way the output of the loud speaker is increased at the same time as the sound wave becomes more planar. The chambers preferably extend over several cells, even if it is possible for each loud speaker cell to have separate chambers that enclose each tube.

If the loud speaker has several loud speaker cells, and even several pressure chambers stacked on each other, a very strong acoustic pressure can be produced without the need for the pressure in the chambers to be especially great. Consequently, the load on the loud speaker will be small, which means that lighter components, thinner walls, etc can be used. This allows not only the loud speaker to be smaller and lighter, but also enhances the sound effect produced.

When several loud speaker cells are used in the same loud speaker they are preferably controlled synchronously. In this way an homogenous sound wave is obtained which is emanated in a direction essentially perpendicular to the plane of the loud speaker, as shown in Fig 3. It is, however, also possible to let the cells work in a somewhat staggered arrangement. Doing this allows the acoustic wave to be controlled so that it has different directions, as is indicated by the dash-dotted acoustic wave. The directional characteristics of the loud speaker can accordingly be controlled via an electronic control unit.

The invention can be used for a variety of purposes, such as, for example, in

traditional hi-fi applications for reproduction of sound. It is, however, specially suitable for active noise suppression, since it has a wide frequency spectrum together with high efficiency, high output per weight and area unit, and in particular high output at low frequencies (15-50 Hz). Furthermore, compressed air, which is used to drive the loud speaker, is often available in such noisy environments where the loud speaker can be used with advantage. By active noise suppression is meant that a signal processing system creates a counter field to a measured field, thereby suppressing the primary sound. The signal processing system can be either adaptive or static.

The loud speaker, for instance, can be used for noise suppression in jet engines, such as turbo-fan engines. Such engines produce sound principally in a forward direction, and noise levels can be extremely high (up to 180 dB). This is a serious environmental problem, and efforts are increasingly being made to overcome this. With the loud speaker according to the invention the loud speaker cells can be placed around the inner wall in the front part of the engine, as shown in Fig 4. The loud speaker according to the invention may suitably be used for this application since the loud speaker can be made extremely small and thin, but still produce strong acoustic pressure with an adequate output, which in this case is necessary. Another, similar application is in gas turbine outlets and the like, where as in the previous case very high noise is created, which requires a high output and often at low frequencies.

Another similar application of the invention is in active noise suppression of noise from exhaust systems in combustion engines.

In Fig 5 an alternative embodiment of the invention is shown, which is particularly suitable for active noise suppression in ventilation ducts, although naturally employable in other situations. Around one tube 51, such as for example a ventilation duct, an outer tube 52 is placed. The inner tube has openings 53 in the side wall,facing the enveloping chambers 54, 55. Some of these chambers preferably have positive pressure while others have

negative pressure. The outer tube, which is able to slide, is arranged between the chambers 54, 55 and the inner tube, and equipped with openings 56. When the outer tube 52 is slid to and fro on the inner tube 51 the openings 53 in the inner tube are alternately exposed for the chamber with positive pressure and the chamber with negative pressure. Naturally, even in this embodiment, more or less chambers can be used, more or less openings, and so on.

The loud speaker according to the invention can be manufactured in many different materials, depending on the intended application, such as metal, plastic or composite material.

The invention has been described above for an embodiment comprising several chambers with alternate positive and negative pressure. It should be realised, however, that the invention can also be used with a tube which can slide in and out of a positive pressure chamber only. It should also be realised that several chambers with alternate positive and negative pressure can be employed. Additionally, the mobile part has been termed a tube. However, it should be realised that even tube shaped parts with a non-circular cross-section are included here. Furthermore, the tube may well include longitudinal ducts which do not extend along the whole tube, but rather a part of it. All such tube shaped parts with longitudinal ducts are considered to be included in the term tube. Moreover, several different drive mechanisms can be used, as well as other types of modulatable openings. These and similar versions of the invention must be considered to be included in the invention as is defined by the attached claims.